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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Amplitude spectra for the fundamental Rayleigh mode and for the combined higher Rayleigh modes are used to infer crustal models of shear wave internal friction for a region of the Middle East between souther Iran and western Turkey. This recently developed method requires only a single source and single receiver; thus, it is useful for obtaining shear wave internal friction models for relatively small regions. The model which provides the best fit to the amplitude spectra throughout most of the Iranian Plateau and Turkey consists of a 20 km thick upper crust with an attenuation value of 85 overlying

a lower crust with a value of about 300 for shear waves. Data for the region around Meshed, Iran, are, however, better explained by a model in which the upper crust is 33 km thick and is comprised of rock having an average shear attenuation value of about 75. To aid in the problems of detecting and identifying underground nuclear explosions in the U.S.S.R. using regional seismic data, a study of Lg waves generated by explosions and earthquakes within the U.S.S.R. was begun. Attenuation of 1-Hz waves was determined using the coda method recently described by Herrmann. Preliminary results indicate that attenuation for 1-Hz Lg waves is approximately 900 for the interior of the U.S.S.R., similar to that in the eastern United States. High mountains and deep seas reduce this value.

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TECHNICAL REPORT SUMMARY

Amplitude spectra for the fundamental Rayleigh mode and for the combined higher Rayleigh modes are used to infer crustal models of shear wave internal friction (Q_β^{-1}) for a region of the Middle East between southern Iran and western Turkey. This recently developed method requires only a single source and single receiver; thus, it is useful for obtaining Q_β^{-1} models for relatively small regions. The model which provides the best fit to the amplitude spectra throughout most of the Iranian Plateau and Turkey consists of a 20 km thick upper crust with a Q_β value of 85 overlying a lower crust with a Q_β value of about 300. Data for the region around Meshed, Iran, are, however, better explained by a model in which the upper crust is 33 km thick and is comprised of rock having an average Q_β value of about 75.

To aid in the problems of detecting and identifying underground nuclear explosions in the U.S.S.R. using regional seismic data, a study of Lg waves generated by explosions and earthquakes within the U.S.S.R. was begun. Attenuation of 1-Hz waves was determined using the coda method recently described by Herrmann. Preliminary results indicate that Q_o for 1-Hz Lg waves is approximately 900 for the interior of the U.S.S.R., similar to that in the eastern United States. High mountains and deep seas reduce the value of Q_o. A study of the excitation (source amplitude) of 1-Hz Lg waves shows that although many explosions have smaller values than earthquakes, a sufficiently large number do not. Thus Lg amplitudes do not appear to be useful as a simple discriminant. They may be useful for explosions in some regions, and not in others. Furthermore, seismograph stations may have to be selected for each region to obtain optimum results.

Multi-mode Rayleigh Wave Attenuation and Crustal Q Structure in Iran and Turkey

by

J.J. Chen and B.J. Mitchell

Introduction

Surface wave attenuation studies have recently become important for studying regional variations of the anelastic properties (or Q^{-1} structure) of the Earth's crust. Q structure beneath oceanic regions appears to differ significantly from that beneath continents (Mitchell et al., 1977) and Q values exhibit large lateral variations within both continental regions (Mitchell, 1975) and oceanic regions (Canas and Mitchell, 1978; Correig and Mitchell, 1979).

Further advances in our knowledge of the nature of regional variations of Q in the crust require relatively short paths, preferably confined to lie within individual tectonic provinces. In order to study such short paths, a new method has recently been developed which employs a single source and a single receiver (Cheng and Mitchell, 1980). The method matches the observed spectra of higher-mode and fundamental-mode Rayleigh waves with theoretical spectra computed for earthquake sources with known depths and focal mechanisms in order to obtain simple two- or three-layer Q^{-1} models of the crust. The method was applied successfully to obtain models of shear wave internal friction (Q_β^{-1}) for the eastern United States, the Colorado Plateau, and the Basin and Range province in North America.

The present study utilizes the same method to study the anelastic properties of the Earth's crust in a complex region of the Middle East, extending from southern Iran to western Turkey. The tectonics of much of that region is thought to result from interactions produced by the collision of the Arabian plate with the Iranian and Turkish plates.

Surface Wave Data

Several earthquake fault-plane solutions in the Middle East were obtained by McKenzie (1972). Some of those events were suitably located for the purposes of the present study. Their locations appear on the map in Figure 1 and their locations and fault parameters are given in Table 1. An example seismogram, exhibiting both higher- and fundamental-mode wave forms is shown in Figure 2.

Continental higher-mode wave forms actually consist of a superposition of several higher modes which travel at similar group velocities. They are therefore impossible to separate from one another using data at a single station. The method of Cheng and Mitchell (1980) makes no attempt to separate the modes from one another in the observational data. Rather, the spectra of the observed higher modes are compared with theoretical higher-mode spectra which are also computed for a superposition of several modes. Care must be taken to include a sufficient number of modes to accurately characterize the higher-mode wave form.

The seismograms are digitized, and spectra for the combined higher modes and fundamental mode are obtained using the multiple-filter method (Dziewonski et al., 1969). Those spectra are then compared with theoretical spectra computed for sources with known fault-plane solutions. In some cases, it is possible to solve separately for the source depth by comparing the shapes of the observed and theoretical fundamental-mode spectra.

The theoretical spectra can be adjusted to achieve a satisfactory fit to the data by varying the parameters of the Q_β^{-1} model. Cheng and Mitchell (1980) found that the shapes and relative spectral levels in the regions they studied were largely controlled by Q_β values in the upper crust. Therefore, if a two-layer model was used, it was possible to achieve a fit by varying only Q_β and the thickness of the upper layer.

Figure 3 presents theoretical spectra for three different Q_β^{-1} models of the crust. The smooth line which extends to longer periods denotes the fundamental-mode Rayleigh wave spectrum, whereas the more oscillatory line corresponds to a superposition of 9 higher modes. The spectra correspond to the eastern United States model and the Basin and Range models of Cheng and Mitchell (1980), and a model similar to the Basin and Range model, but with a much lower value of Q_β in the lower crust. The figure indicates that the eastern United States model and Basin and Range model produce distinctly different spectral levels and shapes. The model with smaller Q_β values in the lower crust, however, produces spectra which differ by a much smaller amount from those of the model with the high-Q lower crust.

Velocity Model

The spectra described in the preceding section were computed using the theory of Levshin and Yanson (1971). In order to compute the spectra, it was necessary to first compute eigen-functions for a presumed velocity-density model for the region. A model was obtained by trial and error which explained the group velocities of the present data set obtained using the multiple-filter method. Those group velocities appear in Figure 4 along with velocities calculated for the derived model. Table 2 lists the parameters of that model. It is quite similar to one of the Colorado Plateau models of Bucher and Smith (1971), except that the sedimentary layer is much thicker than that for the Colorado Plateau model.

The group velocities for the Iran-Turkey region exhibit substantial scatter, presumed to be due to lateral variations in elastic properties in that complex region. It is also expected that lateral refraction and multi-pathing of the Rayleigh waves is substantial. Because of the complexity of the region and the scatter of the data, no attempt was made to determine more detailed velocity models for Iran and Turkey. Previous attenuation studies (e.g. Mitchell, 1975) have shown that Q_β models derived from inversions of attenuation data are not greatly affected by changes in the velocity structure, as long as the velocity model is a reasonable approximation for the region of study.

Q_β^{-1} Models

Amplitude spectra derived for all of the seismograms from the events and stations in Figure 1 and Table 1 appear in Figures 5 and 6. The spectra in Figure 5 correspond to all paths through western and southern Iran and Turkey. Spectra for paths through northeastern Iran appear in Figure 6. These spectra include all seismograms recorded at MSH as well as one seismogram for an earthquake just south of MSH and recorded at IST.

Initially, one Q_β^{-1} model was sought which would explain all sets of spectral data. The observed amplitude data from station MSH, however, were found to lie systematically lower than the theoretical spectra which satisfied the data at most other stations. Satisfactory fits to all of the data required two models, one for northeastern Iran and one for the rest of the region of study.

The model which satisfies the amplitude spectral data throughout most of Iran and Turkey consists of a 20 km thick layer having Q_β values of 85 overlying a half-space having values of 300. The model corresponding to northeastern Iran includes a low Q upper crust which is thicker (33 km) and consists of lower Q_β values (75) than the model for most of the region (Figure 7).

Discussion and Conclusions

Q_β values throughout the crust in the Middle East are substantially lower than those obtained in stable continental regions such as eastern North America (Mitchell, 1973; Herrmann and Mitchell, 1975). Values in the upper crust are similar to those in the Basin and Range province of the western United States. Some lateral variation in Q_β in the upper crust seems to occur with a region in northeastern Iran having somewhat lower values (75) than other areas of this study.

Q_β values for the lower crust of about 300 best explain the available spectral data. The spectra are, however, much less sensitive to the properties of the lower crust than they are to those of the upper crust, so the lower crustal value must not be considered well determined.

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Figure Captions

Figure 1. Map of a portion of the Middle East showing the locations of the earthquakes and seismograph stations used in this study. The numbers refer to the earthquakes in Table 1.

Figure 2. An example seismogram. F denotes the appropriate onset of the fundamental Rayleigh mode and H denotes the approximate onset of a superposition of several higher modes.

Figure 3. Theoretical amplitude spectra for three Q_β models of the crust. The interface between the upper and lower crustal layers is taken to be at a depth of 20 km. The smooth curves extending to a period of 100 s correspond to the fundamental mode, whereas the more oscillatory curves at shorter periods result from a superposition of 9 higher modes. The curves are smoothed through rapidly oscillating values for periods less than 5 s.

Figure 4. Group velocity values for six of the earthquakes used in this study. The solid curve indicates the theoretical group velocities for the model of Table 2.

Figure 5. Observed (symbols) and theoretical (lines) spectra corresponding to Rayleigh waves recorded at stations IST, SHI, and TAB. The circles denote the fundamental mode and the squares denote the higher modes. The theoretical spectra were computed for the source parameter in Table 1 and a Q model in which Q_β has a value of 85 in the upper 20 km of the crust and 300 at greater depths (see Figure 7).

Figure 6. Observed and theoretical spectra corresponding to Rayleigh waves recorded at station MSH as well as one recording at station IST. The theoretical spectra were computed for the source parameters in Table 1 and a Q model in which Q_β has a value of 75 in the upper 33 km of the crust and 300 at greater depths (see Figure 7).

Figure 7. Q_β models for the Iran-Turkey region. The solid line indicates a two-layer model which explains the Rayleigh wave spectral amplitudes throughout most of Iran and Turkey. The dashed model pertains to a region surrounding station MSH.

TABLE 1

EARTHQUAKE PARAMETERS

Event Number	Date	Origin Time (h m s)	Lat. (N)	Long. (E)	Depth (km)	m_b	Moment	Focal Mechanisms* Dip	Slip	Strike	Stations
1	27 APR 66	19 48 52.4	38.20	42.50	11	5.0	1.950×10^{24}	74	24	292	IST, MSH, SHI
2	27 JUL 66	14 49 02.1	32.60	48.80	13	5.3	1.826×10^{24}	34	119	294	MSH
3	18 SEP 66	20 43 53.8	27.90	54.30	15	5.9	1.540×10^{24}	34	98	270	TAB
4	11 JAN 67	11 20 45.7	34.10	45.70	15	5.6	2.200×10^{24}	40	100	334	IST, MSH
5	07 APR 67	18 33 31.3	37.40	36.20	10	5.0	0.400×10^{24}	90†	90†	45†	IST, MSH, SHI
6	29 APR 68	17 01 57.6	29.20	44.30	15	5.3	2.300×10^{24}	70	25	59	IST, MSH
7	04 SEP 68	23 24 47.2	33.90	58.24	18	5.4	1.333×10^{24}	25	90	147	IST

*Focal mechanisms are taken from McKenzie (1972).

†Assumed from sparse data.

TABLE 2

Iran-Turkey Crust-Upper Mantle Model

Layer Thickness	Compressional Velocity	Shear Velocity	Density
2.5	3.00	1.73	2.40
26.0	6.20	3.58	2.83
13.0	6.80	3.87	2.99
45.0	7.80	4.25	3.30
--	8.20	4.38	3.43

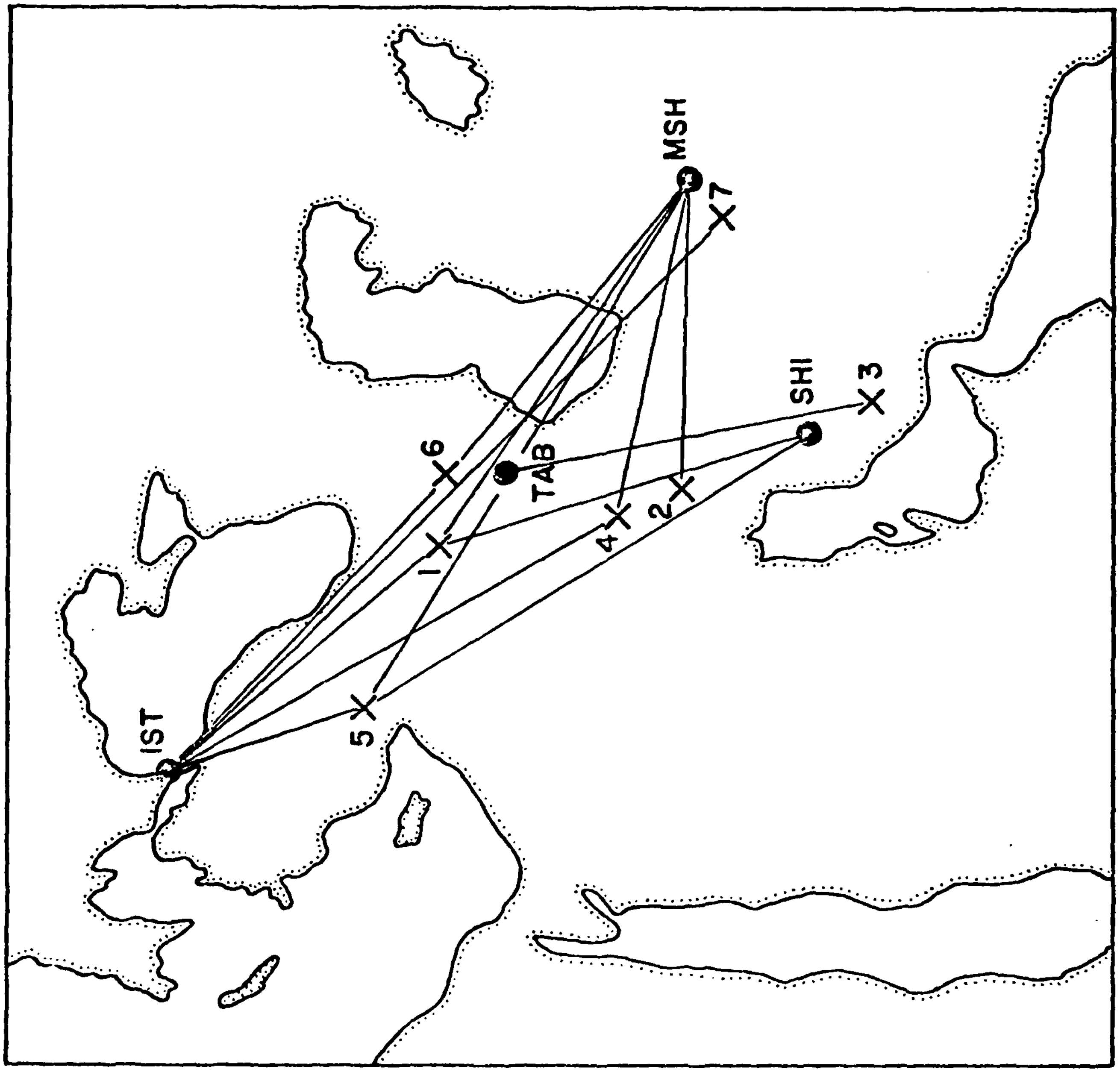


Figure 1

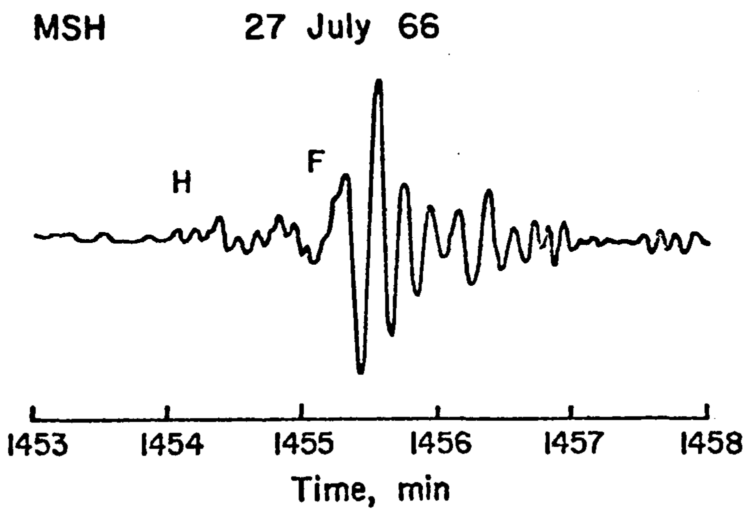


Figure 2

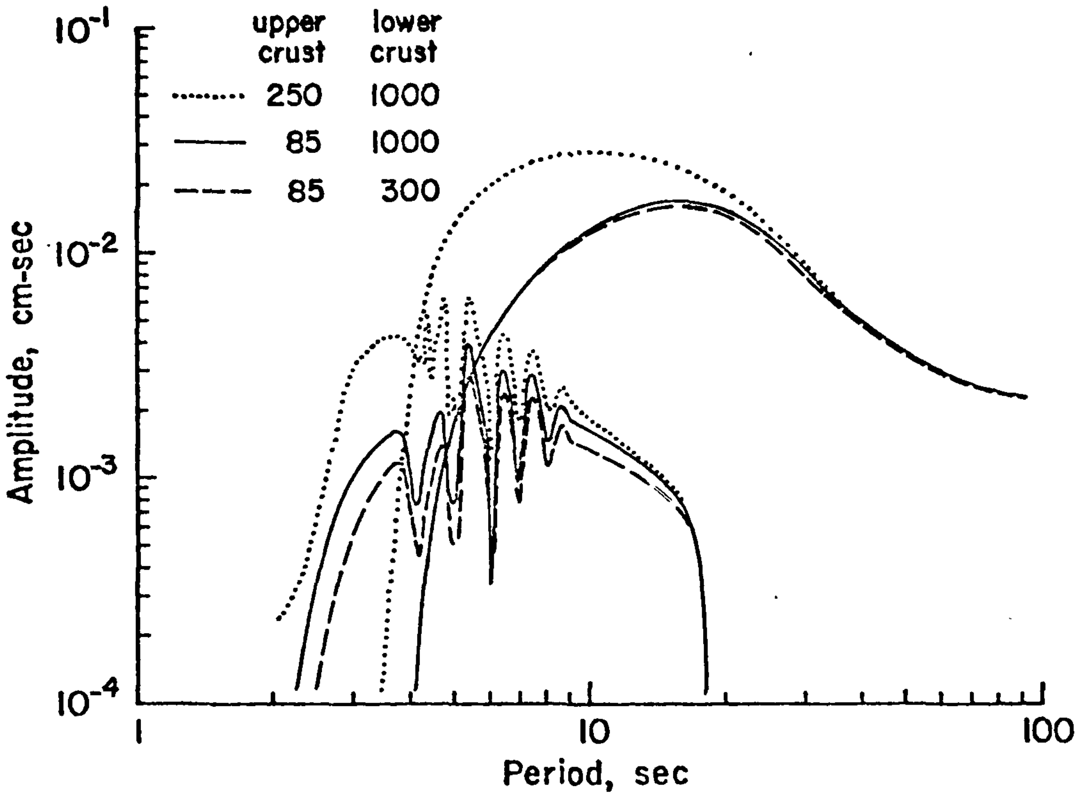

upper crust
lower crust
250
1000
85
1000
85
300
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Amplitude, cm-sec
1
10
100
Period, sec

Figure 3

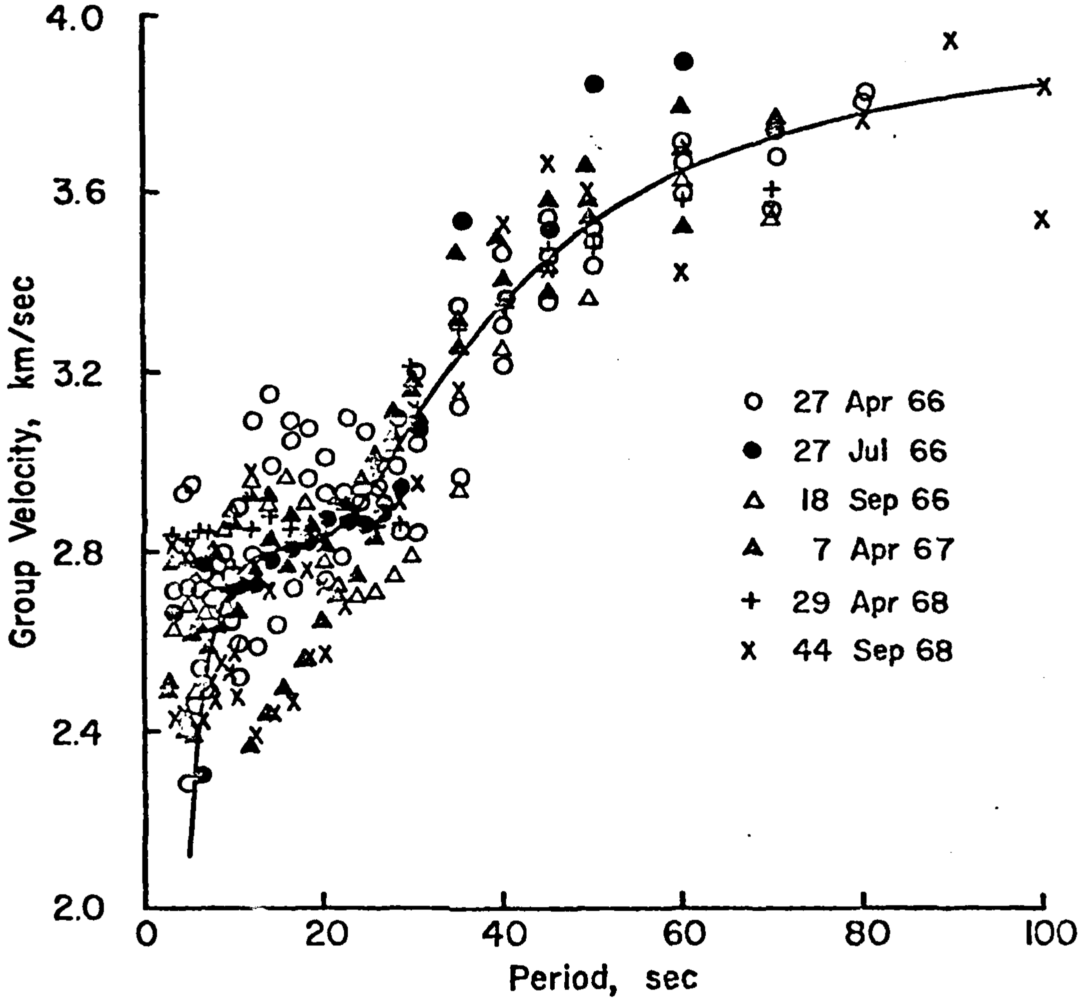
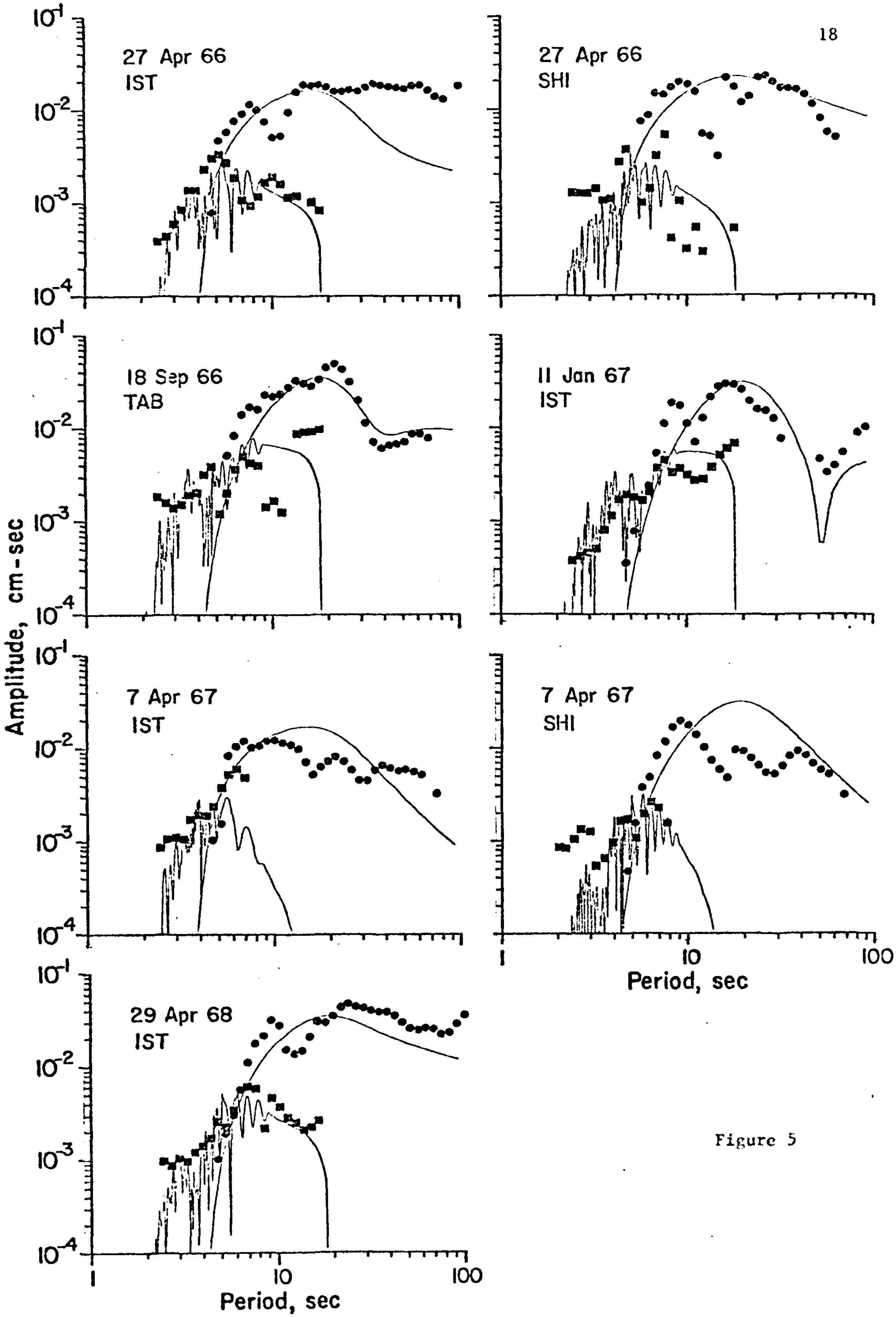

4.0
3.6
3.2
2.8
2.4
2.0
Group Velocity, km/sec
0
20
40
60
80
100
Period, sec
27 Apr 66
27 Jul 66
18 Sep 66
7 Apr 67
29 Apr 68
44 Sep 68

Figure 4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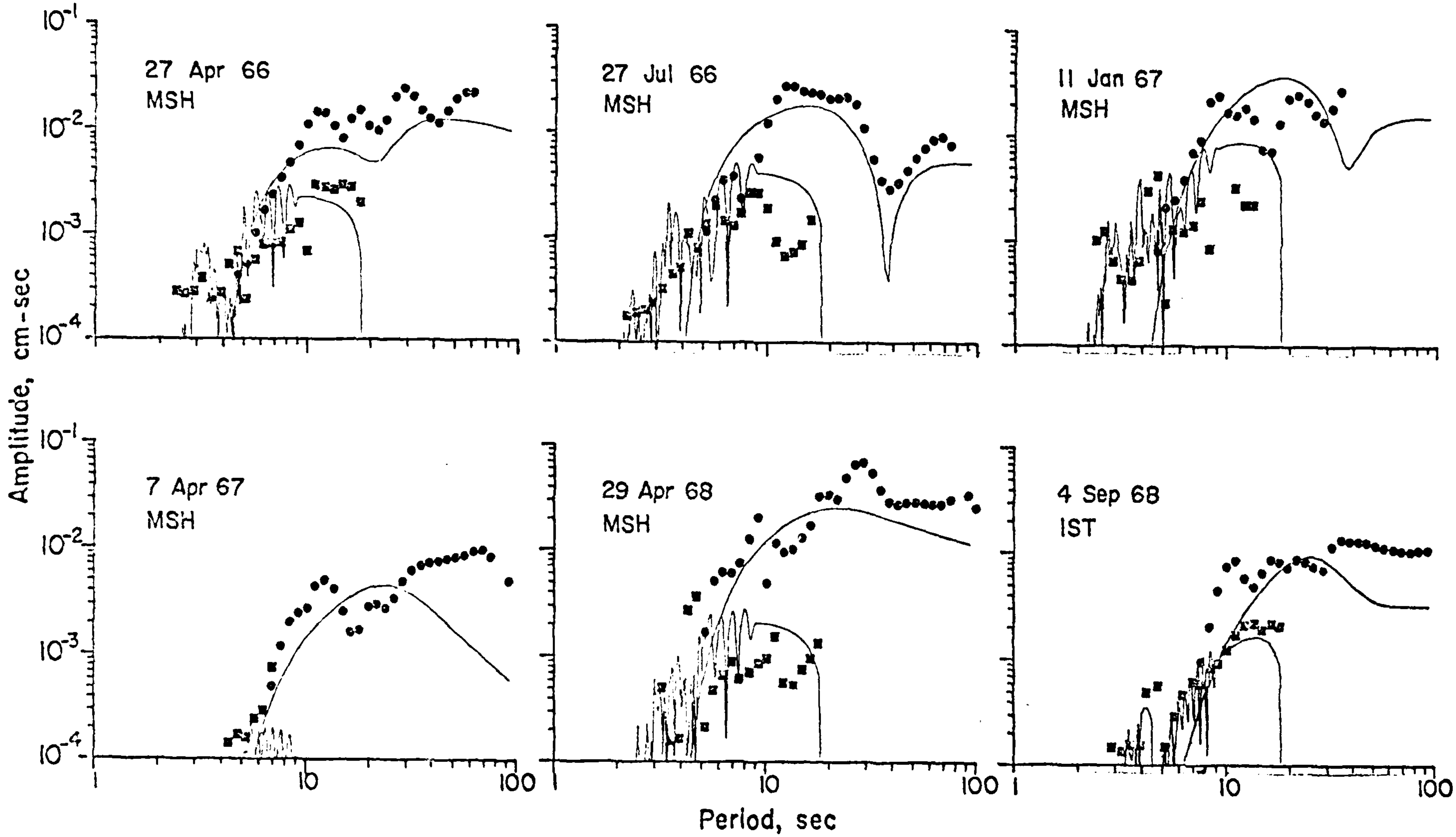
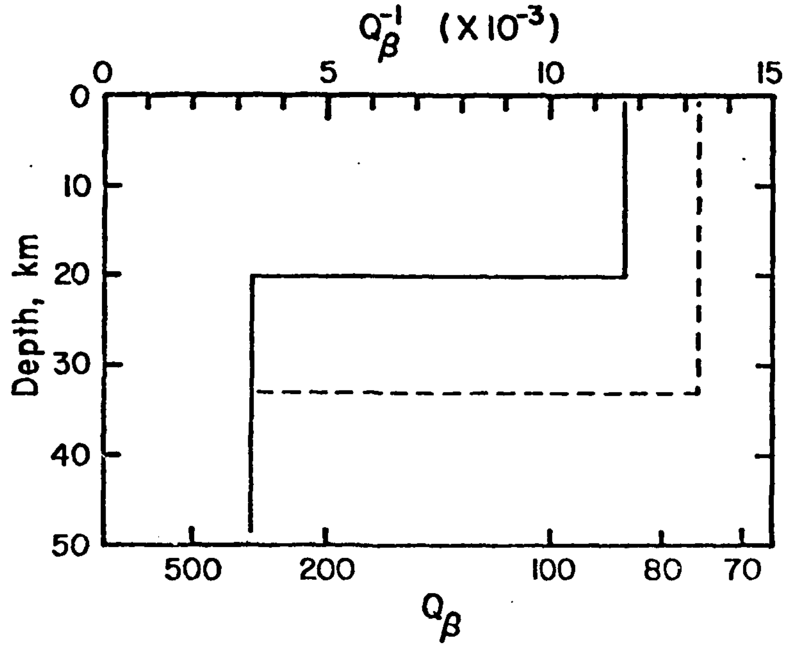
IST
27 Apr 66
SHI
18 Sep 66
TAB
11 Jan 67
IST
7 Apr 67
IST
7 Apr 67
SHI
29 Apr 68
IST
Amplitude, cm-sec
Period, sec
10^-1
10^-2
10^-3
10^-4
1
10
100

Figure 5



27 Apr 66
MSH
27 Jul 66
MSH
11 Jan 67
MSH
7 Apr 67
MSH
29 Apr 68
MSH
4 Sep 68
IST
Amplitude, cm-sec
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
100
Period, sec

Figure 6



Q_β^{-1} (X 10^{-3})
0
5
10
15
0
10
20
30
40
50
Depth, km
500
200
100
80
70
Q_β

Figure 7

ON THE EXCITATION AND ATTENUATION OF 1-Hz Lg WAVES FROM SOURCES IN THE U.S.S.R.

by

Otto W. Nuttli

INTRODUCTION

Short-period Lg waves potentially are among the most useful waves recorded at regional distances to detect and locate underground explosions. Also, they have been proposed as a discriminant, and possibly as a means of estimating the yield of the explosions. Most of the studies to date of Lg have been empirical in nature, which makes it difficult to extend results from one province to another. An advantage of having in addition a theoretical model is the ability to predict results. At present we are in the state of testing predictive models against observational data.

Nuttli (1980) has observed that the source amplitude (actually the extrapolation back to 10 km epicentral distance of Lg amplitudes observed at greater distances) is practically independent of earthquake source region. That is, earthquakes of $m_b = 5.0$ have an extrapolated Lg-wave amplitude of approximately 200 microns (vertical component of motion) at 10 km distance, regardless of whether the earthquakes occur in eastern North America, southern Asia or Iran. This means that the amplitudes of 1-Hz Lg waves, when properly corrected for the effects of attenuation, are proportional to m_b in the same way that P waves are. Springer and Nuttli (1980) and Nuttli (1980) used this observation to estimate average values of the coefficient of anelastic attenuation for 1-Hz Lg waves, using a single observation of Lg amplitude at a station and the m_b value of the earthquake, as determined from teleseismic observations. This method cannot be used for Lg waves from explosive sources, however, because the relation between P and Lg amplitudes in the source region may not be the same for earthquakes and explosions. In fact, the use of Lg/P wave amplitudes as a discriminant implies that there is a notable difference in the source amplitudes of Lg waves from earthquakes and explosions which have the same P-wave m_b value. In this report we shall look at the excitation of Lg waves from explosive sources in the U.S.S.R., and compare the results with earthquake data.

The ability to determine Lg-wave attenuation and excitation information from explosive sources in the U.S.S.R. is difficult for two reasons. The first has been mentioned above, and thus precludes the use of amplitude data from a single station to obtain values of the coefficient of anelastic attenuation (γ) from various sources to the station. (In the future, for the sake of brevity, we shall refer to the specific quality factor, Q, instead of γ. They are related by $Q = \pi f/u\gamma$, where f is the wave frequency and u is the group velocity.) The second is that western seismologists do not have available to them a large number of Lg amplitudes observed over a range of epicentral distances for single events. If such data were available, they could be used in the manner first proposed by Nuttli (1973) to determine Q and source excitation values.

Because the traditional methods of determining Q and source excitation cannot be used for explosion sources in U.S.S.R., we shall have to employ some alternative means of obtaining Q values. Recently, Herrmann (1980) has proposed just such a method. The method utilizes the change in wave frequency with arrival time in the Lg coda, and thus is independent of amplitude observations. It can be used for data from a single station for a single source, although it is better to average data from many sources located near each other if such data are available. Herrmann's method is the method used in the present study to estimate Q values.

There is one uncertainty which arises in the application of Herrmann's (1980) method that must be resolved before the method can be applied. If the value of Q varies with the wave frequency, then there is one additional parameter which enters into the relation between Q and the change of wave frequency with arrival time in the Lg coda. Mitchell (1980) and Aki (1980) have concluded that Q is dependent on wave frequency, in the form $Q = Q_o f^{\zeta}$, where Q_o is the value of Q at 1 Hz, f is the frequency and ζ is a dimensionless quantity. For Rayleigh waves in the period range 1 to 10 sec, Mitchell (1980) obtains ζ values of 0.3 to 0.5 for earthquakes in eastern North America. For S body waves in Japan, Aki (1980) obtains for two regions $\zeta = 0.8$ and $\zeta = 0.6$ for the frequency range of 1 to 25 Hz. He notes that Rautian and Khalturin obtained $\zeta = 0.5$ for S waves observed at Garm in central Asia, and that Fedotov and Boldyrev obtained a ζ value of 0.6 for S waves recorded in the Kurils.

For the present study, the coda data from U.S.S.R. explosions were not adequate to evaluate ζ, and could only suggest that ζ lies between 0 and 0.5. However, the U.S.S.R. earthquake data proved useful. Their coda-arrival time relations were used to estimate Q_o, assuming ζ values of 0, 0.1, 0.2, 0.3, 0.4 and 0.5. Then their 1-Hz Lg amplitudes were extrapolated back to 10 km epicentral distance, for each of the assumed values of ζ. The ζ value which gave a 10 km amplitude of approximately 200 microns for an $m_b = 5.0$ earthquake was taken to be the proper value of ζ. For the limited amount of earthquake data available, the value of 0.2 appears to be most suitable. The value $\zeta = 0.5$, for example, gives a source amplitude ten times too large. Film copies of seismograms of more U.S.S.R. earthquakes have been ordered, and in future study they will be used to get a better estimate of ζ.

Q_o AND γ VALUES FOR THE U.S.S.R.

Herrmann's (1980) coda method was applied to the data of a number of explosions and earthquakes, to obtain estimates of Q and γ for 1-Hz Lg waves. The results are displayed graphically in Figures 1 to 7, and are given more completely in Tables 1 to 8. All of these results assume that $\zeta = 0.2$.

The figures show that Q_o is greatest in the interior of the U.S.S.R. (attenuation is the lowest), and that attenuation increases as the path includes more of the mountainous regions of southern Asia. The values of Q_o to the Scandinavian stations in general are relatively high, but decrease as the path length across the seas increases. By way of comparison, Q_o for 1-Hz Lg waves has a value of 1200 in the central United States, 900 for the eastern United States, 200 for California and 200 for Iran, approximately. From Figures 1 to 7 it appears that Q_o for the interior of the U.S.S.R. is most similar to that of the eastern United States.

In Tables 1 to 8 the n-value is the number of stations used to obtain a particular Q_o value. To obtain the average, the values of $1/Q_o$, rather than Q_o, were used. The numbers in parentheses after Q_o give values corresponding to $\pm$ one standard deviation of $1/Q_o$.

During the next six-month period more data for U.S.S.R. explosions and earthquakes will be analyzed. One purpose is to determine if $\zeta = 0.2$ is the most appropriate value to use. In addition, the more abundant data will allow us to construct a generalized Q_o map for the U.S.S.R. This can be used to derive m_b formulas for various parts of the country, which will be useful in determining detection thresholds.

EXCITATION OF Lg WAVES

Once the value of γ has been determined for the path from a particular source to a particular station, it is then possible to calculate the source excitation for the Lg wave, by using the formula

$$A(\Delta) = A_o \, (\sin \Delta)^{-1/2} \, (\Delta)^{-1/3} \, \exp(-\gamma\Delta)$$

where $A(\Delta)$ is the ground amplitude at the distance Δ and A_o is the source amplitude. This procedure was carried out for all the amplitude data. All earthquakes were equalized to an m_b of 5.0, by assuming that $\log_{10} A(\Delta)$ is directly proportional to m_b. The results are shown in Tables 9 to 16.

In general, earthquakes of $m_b = 5.0$ are expected to have an A_o value of 100 to 300, based on studies of earthquakes in eastern North America, southern Asia and Iran. An inspection of Table 16 (eastern Caucasus earthquakes) and Table 11 (one central Kazakhstan earthquake) shows that this is the case for the U.S.S.R. earthquakes studied.

From Table 9, it can be seen that KBL and KEV have very low amplitude Lg waves, about one-tenth those of earthquakes of comparable m_b value. At NUR all the Lg amplitudes are as large as those for an earthquake. LAH, ESK and STU have very large Lg amplitudes, whereas NOR, COP, KON and UME have intermediate values. Depending upon the choice of stations selected, one could argue that the Lg waves do or do not allow one to identify Novaya Zemlya events as explosions.

Table 10 shows that most Eastern Kazakhstan explosions would be identified as such, although NIL and NUR have earthquake-like Lg amplitudes. KBL in particular has very small Lg amplitudes. Gupta and Burnetti (1980) observed that the P/Lg amplitude ratio was an effective discriminant for eastern Kazakhstan explosions recorded at KBL.

All three of the central Kazakhstan explosions could be identified as explosions on the basis of their Lg amplitudes, as given in Table 11. However, for the western Kazakhstan explosions, the data of Table 12 allow only one of the three explosions to be classifed as such. Those of August 20, 1972 and November 24, 1972 would be incorrectly labeled as earthquakes on the basis of observed Lg amplitudes.

There are very limited data available for the Ural Mountains explosions. From Table 13, the March 23, 1971 event would be classified incorrectly as an earthquake, and possibly also the August 29, 1974 event. The other two would be correctly identified, using the small amount of data available. The western Siberian explosion of August 14, 1974 would be identified as an explosion on the basis of the data given in Table 14.

The western Russia explosion data given in Table 15 show that KBL has very small Lg amplitudes, but that KEV, NUR and UME have very large amplitudes for some events. On the basis of the data given in the table, probably at least four of the eight events would be incorrectly classified as earthquakes (October 22, 1971; September 21, 1972; November 24, 1972; and September 30, 1973).

The above findings are consistent with those of Pomeroy (1980), who concluded that the P/Lg amplitude ratio probably was useful at most on a regional basis in the U.S.S.R., if at all.

CONCLUSIONS

A study of Lg amplitudes of seismic events in the U.S.S.R. (principally underground nuclear explosions) showed that the attenuation of 1-Hz Lg waves varies with geographic region. Not surprisingly, high mountainous areas and deep seas are regions where Lg is more severely attenuated. For the interior of the U.S.S.R., the approximate Q_o value is 900, similar to that for the eastern United States but a little less than that for the central United States.

From a study of the excitation of 1-Hz Lg waves, it is found that the majority of U.S.S.R. explosions had Lg source amplitudes smaller than those of earthquakes, so that Lg could be used as a discriminant for them. However, there was a fairly large number of explosive events which had Lg waves of amplitudes similar to those of earthquakes, so that for them Lg would not serve as a discriminant. If the ratio of P/Lg amplitudes is intended to be used for discrimination purposes, it may have to be done very selectively, using only certain stations for certain zones. The problem requires much more attention, and we intend to pursue it in the coming six months.

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TABLE 1

Q_o AND γ VALUES FOR NOVAYA ZEMLYA EXPLOSIONS

EXPLOSION PARAMETERS

Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b	Remarks
Oct. 27, 1966	06^h00^m	73.04	54.57	6.4	
Oct. 14, 1970	06 00	73.31	54.89	6.6	
Sep. 12, 1973	07 00	73.32	54.97	6.8	
Sep. 27, 1973	07 00	70.80	53.42	5.9	
Oct. 27, 1973	07 00	70.80	53.92	6.9	
Oct. 27, 1973	08 21	71.00	52.60	4.6	crater or aftershock
Oct. 27, 1973	09 13	71.24	51.80	4.6	crater or aftershock
Aug. 29, 1974	10 00	73.41	54.93	6.4	

ATTENUATION PARAMETERS

Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
COP	1.75×10^{-3}	3	8.37×10^{-4}	572(387,1097)	1.57×10^{-3}
ESK	1.85	1		540	1.66
KBL	1.52	3	6.34	659(465,1131)	1.36
KEV	2.04	11	9.43	491(335,912)	1.83
KON	1.77	2	0.66	565(544,587)	1.59
LAH	1.82	2	0.47	550(536,564)	1.63
NOR	2.81	4	8.10	355(276,499)	2.53
NUR	2.51	11	9.39	399(290,637)	2.25
STU	1.80	2	5.27	555(429,784)	1.62
UME	2.39	9	12.69	418(273,892)	2.15

TABLE 2

Q_o AND γ VALUES FOR EASTERN KAZAKHSTAN EXPLOSIONS

EXPLOSION PARAMETERS

Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
Nov. 16, 1964	06^h00^m	49.80	78.17	5.5
Mar. 25, 1967	05 58	49.78	78.06	5.3
Sep. 22, 1967	05 04	50.02	77.72	5.2
Feb. 16, 1973	05 03	49.86	78.23	5.5
Apr. 19, 1973	04 33	49.99	77.69	5.4
Jul. 10, 1973	01 27	49.82	78.09	5.2
Jul. 23, 1973	01 23	49.94	78.85	6.1
Oct. 26, 1973	04 27	49.74	78.18	5.2
Dec. 14, 1973	07 47	50.03	79.02	5.8
Jan. 30, 1974	04 57	49.89	78.11	5.4
May 16, 1974	03 03	49.74	78.12	5.2
May 31, 1974	03 27	49.91	78.91	5.9
Jul. 10, 1974	02 57	49.77	78.15	5.2
Sep. 13, 1974	03 03	49.76	78.03	5.2
Oct. 16, 1974	06 33	49.99	78.96	5.5
Dec. 07, 1974	06 00	49.92	77.65	4.7
Dec. 16, 1974	06 23	49.81	78.09	5.0
Dec. 16, 1974	06 41	49.86	78.15	4.8
Dec. 27, 1974	05 47	49.91	79.05	5.6

ATTENUATION PARAMETERS

Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
KBL	1.68×10^{-3}	18	6.10×10^{-4}	594(420,931)	1.51×10^{-3}
KEV	1.18	3	1.70	845(741,990)	1.06
KOD	0.83	1		1200	0.75
MSH	1.54	4	1.49	651(593,721)	1.38
NDI	1.20	2	0.71	834(787,886)	1.08
NIL	2.29	19	6.19	436(344,598)	2.06
NUR	1.28	6	1.43	781(702,878)	1.15
QUE	1.74	8	2.97	574(491,692)	1.55
SHI	1.70	1		590	1.52
SHL	1.55	2	0.18	645(638,652)	1.39
TAB	1.72	1		580	1.55
UME	1.23	3	1.57	814(722,924)	1.10

TABLE 3

Q AND γ VALUES OF CENTRAL KAZAKHSTAN EXPLOSIONS

EXPLOSION PARAMETERS

No.	Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b	Comments
1	Aug. 15, 1973	02^h00^m	42.69	67.41	5.3	
2	Aug. 28, 1973	03 00	50.58	68.40	5.2	
3	Sep. 19, 1973	03 00	45.68	67.80	5.1	
4	Apr. 13, 1974	08 59	42.03	69.10	4.5	Earthquake

ATTENUATION PARAMETERS

No.	Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
1	MSH		1		310	2.90×10^{-3}
	NUR		1		1500	0.60
	QUE		1		370	2.43
	SHI		1		380	2.36
	TAB		1		660	1.36
	UME		1		1000	0.90
2	KBL		1		760	1.18
	NUR		1		650	1.38
	QUE		1		540	1.66
	UME		1		800	1.12
3	KBL	2.30×10^{-3}	2	1.12×10^{-4}	434(414,457)	2.07
	MSH	1.49	2	8.36	670(434,1524)	1.34
	NIL	2.91	3	3.32	344(308,388)	2.61
	QUE		1		390	2.30
	UME		1		620	1.45
4	KBL		1		400	2.24
	MSH		1		330	2.72
	NIL		2	0	245	3.66
	QUE		1		360	2.49

TABLE 4

Q_o AND γ VALUES OF WESTERN KAZAKHSTAN EXPLOSIONS

EXPLOSION PARAMETERS

No.	Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
1	Dec. 22, 1971	07^h00^m	47.90	48.07	6.0
2	Aug. 20, 1972	03 00	49.40	48.06	5.7
3	Nov. 24, 1972	10 00	51.85	64.18	5.2

ATTENUATION PARAMETERS

No.	Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
1	KEV		1		910	0.99×10^{-3}
	MSH	2.23×10^{-3}	2	5.76×10^{-4}	449(357,606)	2.00
	NUR	1.36	2	1.04	738(685,799)	1.22
	QUE		1		630	1.42
	SHI		1		500	1.80
2	KEV		1		620	1.45
	MSH		1		520	1.73
	NIL	2.03	2	2.03	493(448,547)	1.82
	NUR		1		400	2.24
	UME		2	0	550	1.63
3	MSH		1		590	1.52
	NUR		1		630	1.42
	UME		1		710	1.26

TABLE 5

Q_o AND γ VALUES OF URAL MOUNTAINS EXPLOSIONS

EXPLOSION PARAMETERS

No.	Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
1	Mar. 23, 1971	07^h00^m	61.39	56.22	5.5
2	Jul. 02, 1971	17 00	67.66	62.00	4.7
3	Oct. 25, 1973	06 00	53.63	55.78	4.8
4	Aug. 29, 1974	15 00	67.23	62.10	5.0

ATTENUATION PARAMETERS

No.	Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
1	NUR	2.12×10^{-3}	2	2.85×10^{-4}	471(415,544)	1.91×10^{-3}
	UME	1.60	2	0.91	624(590,662)	1.44
2	UME		1		570	1.57
3	KEV		1		610	1.47
	NUR		1		530	1.69
4	COP		1		1150	0.78
	KON		1		480	1.87

TABLE 6

Q_o AND γ VALUES OF WESTERN SIBERIA EXPLOSION

EXPLOSION PARAMETERS

Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
Aug. 14, 1974	15^h00^m	68.94	75.83	5.4

ATTENUATION PARAMETERS

Station	n	Q_o	$\gamma(km^{-1})$
KEV	1	630	1.42×10^{-3}
KON	1	1000	0.69
NUR	1	550	1.63

TABLE 7

Q_o AND γ VALUES OF WESTERN RUSSIA EXPLOSIONS

EXPLOSION PARAMETERS

No.	Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
1	Jul. 10, 1971	17^h00^m	64.20	54.77	5.2
2	Sep. 19, 1971	11 00	57.76	41.40	4.5
3	Oct. 04, 1971	10 00	61.61	47.22	4.6
4	Oct. 22, 1971	05 00	51.61	54.45	5.2
5	Sep. 04, 1972	07 00	67.73	33.10	4.6
6	Sep. 21, 1972	09 00	52.19	51.94	5.0
7	Nov. 24, 1972	09 00	52.14	51.80	4.5
8	Sep. 30, 1973	05 00	51.66	54.54	5.2

ATTENUATION PARAMETERS

No.	Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
1	NUR		1		570	1.57×10^{-3}
	UME		1		660	1.36
2	KEV		1		670	1.34
	NUR		1		340	2.64
	UME		1		450	1.99
3	KEV		1		420	2.14
	NUR	2.10×10^{-3}	3	2.20×10^{-4}	476(431,532)	1.89
4,8	KBL		1		500	1.80
	KEV	1.92	2	2.33	521(465,593)	1.72
	NIL		1		420	2.14
	NUR	2.14	2	1.93	468(4.29,515)	1.92
	UME		2	0	520	1.73
5	NUR		1		1800	0.50
	UME		1		1500	0.60
6	KEV		1		520	1.73
	NUR		1		410	2.19
	UME		1		600	1.50
7	NUR		1		540	1.66
	UME		1		540	1.66

TABLE 8

Q_o AND γ VALUES FOR EARTHQUAKES IN EAST CAUCASUS

EARTHQUAKE PARAMETERS

No.	Date	Origin Time (U.T.)	Lat. (°N)	Long. (°E)	m_b
1	Feb. 03, 1972	02^h29^m	40.74	48.45	5.1
2	Aug. 31, 1973	04 57	43.28	45.32	4.7
3	Aug. 04, 1974	15 06	42.36	45.97	5.4
4	Nov. 13, 1974	02 36	42.90	46.56	5.1
5	Dec. 23, 1974	05 22	43.16	46.94	4.8

ATTENUATION PARAMETERS

No.	Station	$1/Q_o$	n	S.D. of $1/Q_o$	Q_o	$\gamma(km^{-1})$
1	KBL		1		280	3.21×10^{-3}
	MSH		1		390	2.30
	NUR		1		610	1.47
	QUE		1		280	3.21
	SHI		1		220	4.08
	TAB		1		150	5.98
	UME		1		680	1.32
2	NUR		1		540	1.66
	UME		1		600	1.50
3	COP		1		650	1.38
	KBL		1		440	2.04
	NUR	1.69×10^{-3}	2	4.46×10^{-4}	593(469,807)	1.91
	SHI		1		300	2.99
4	KBL		1		330	2.72
	MSH		1		290	3.10
	NUR		1		540	1.66
	QUE		1		400	2.24
	SHI		1		300	2.99
	TAB	5.32	2	7.92	188(164,221)	4.77
5	KBL		1		340	2.64
	NUR		1		900	1.00

TABLE 9

SOURCE AMPLITUDES FOR NOVAYA ZEMLYA EXPLOSIONS,
EQUALIZED TO m_b = 5.0

Date	Station	A_o (microns)	Comments
Oct. 27, 1966	COP	68.1	
	ESK	2059.0	
	KEV	14.9	
	KON	57.0	
	NUR	61.9	
	STU	273.5	
Oct. 14, 1970	KBL	18.1	
	LAH	2794.0	
	NOR	82.8	
Sep. 12, 1973	NUR	138.8	
Sep. 27, 1973	KEV	21.7	
	NUR	331.0	
	UME	90.1	
Oct. 27, 1973	KEV	12.8	crater or aftershock
	UME	51.8	
Oct. 27, 1973	KEV	15.7	crater or aftershock
	UME	57.5	
Aug. 29, 1974	KEV	15.7	
	NUR	229.6	

TABLE 10

SOURCE AMPLITUDES FOR EASTERN KAZAKHSTAN EXPLOSIONS, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Nov. 16, 1964	NDI	1.45
	QUE	4.11
Mar. 25, 1967	NDI	2.69
Sep. 22, 1967	KOD	27.40
Feb. 16, 1973	KBL	8.57
	MSH	35.70
	NIL	30.00
	QUE	38.80
Apr. 19, 1973	NIL	82.50
	NUR	14.60
Jul. 10, 1973	KBL	6.60
	NIL	203.70
	TAB	25.20
Jul. 23, 1973	KBL	43.40
	KEV	17.00
	NIL	171.10
	NUR	99.70
	QUE	15.30
	SHI	40.10
	TAB	174.60
	UME	62.20
Oct. 26, 1973	NIL	25.70
Dec. 14, 1973	NIL	37.60
	NUR	42.50
	SHI	58.40
	SHL	12.20
	UME	56.40
Jan. 30, 1974	KBL	4.58
	NIL	22.90
May 16, 1974	KBL	8.03
	NIL	67.20
May 31, 1974	KEV	10.10
	NUR	113.00
	QUE	9.04
	UME	68.80

Date	Station	A_o (microns)
Jul. 10, 1974	KBL	7.78
	NIL	20.50
Sep. 13, 1974	NIL	20.50
Oct. 16, 1974	KEV	7.59
	NIL	262.60
	NUR	30.60
Dec. 07, 1974	KBL	6.65
Dec. 16, 1974	KBL	10.71
Dec. 16, 1974	KBL	4.85
	NIL	74.30
Dec. 27, 1974	KBL	18.30
	MSH	33.10
	NIL	162.40
	NUR	136.00
	SHL	6.37
	QUE	8.70

TABLE 11

SOURCE AMPLITUDES FOR CENTRAL KAZAKHSTAN EXPLOSIONS, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)	Comments
Aug. 15, 1973	MSH	54.70	
	NUR	3.00	
	QUE	10.70	
	SHI	95.00	
	TAB	11.10	
	UME	18.60	
Aug. 28, 1973	KBL	4.16	
	NUR	74.50	
	QUE	11.80	
	UME	14.70	
Sep. 19, 1973	KBL	21.30	
	MSH	55.10	
	NIL	8.61	
	QUE	16.30	
	UME	493.70	
Apr. 13, 1974	MSH	239.80	Earthquake
	NIL	848.80	
	QUE	18.40	

TABLE 12

SOURCE AMPLITUDES FOR WESTERN KAZAKHSTAN EXPLOSIONS, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Dec. 22, 1971	KEV	6.53
	MSH	16.50
	NUR	13.80
	QUE	1.81
	SHI	5.54
Aug. 20, 1972	KEV	269.00
	MSH	19.40
	NIL	114.00
	NUR	696.20
	UME	537.50
Nov. 24, 1972	MSH	38.90
	NUR	163.30
	UME	111.60

TABLE 13

SOURCE AMPLITUDES OF URAL MOUNTAIN EXPLOSIONS, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Mar. 23, 1971	NUR	227.8
	UME	193.8
Jul. 02, 1971	UME	18.8
Oct. 26, 1973	KEV	46.4
	NUR	72.7
Aug. 29, 1974	COP	27.8
	KON	196.5

TABLE 14

SOURCE AMPLITUDES FOR WESTERN SIBERIA EXPLOSION, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Aug. 14, 1974	KEV	10.0
	KON	12.1
	NUR	51.9

TABLE 15

SOURCE AMPLITUDES OF WESTERN RUSSIA EXPLOSIONS, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Jul. 10, 1971	NUR	32.1
	UME	36.9
Sep. 19, 1971	KEV	43.6
	NUR	140.2
	UME	89.4
Oct. 04, 1971	KEV	152.4
	NUR	71.8
Oct. 22, 1971	KBL	4.4
	KEV	459.3
	NUR	354.6
	UME	36.1
Sep. 04, 1972	NUR	82.8
	UME	61.9
Sep. 21, 1972	KEV	114.8
	NUR	294.6
	UME	102.0
Nov. 24, 1972	NUR	177.2
	UME	242.1
Sep. 30, 1973	KBL	4.4
	KEV	459.3
	NUR	354.6
	UME	36.1

TABLE 16

SOURCE AMPLITUDES FOR EASTERN CAUCASUS EARTHQUAKES, EQUALIZED TO $m_b = 5.0$

Date	Station	A_o (microns)
Feb. 03, 1972	KBL	138.6
	MSH	66.2
	NUR	96.0
	QUE	109.9
	SHI	444.4
	TAB	830.9
	UME	96.6
Aug. 31, 1973	NUR	235.8
	UME	335.5
Aug. 04, 1974	COP	133.7
	KBL	43.2
	NUR	431.6
	SHI	68.7
Nov. 13, 1974	KBL	86.5
	MSH	327.2
	NUR	109.6
	QUE	29.9
	SHI	48.8
	TAB	61.0
Dec. 23, 1974	KBL	374.4
	NUR	33.9

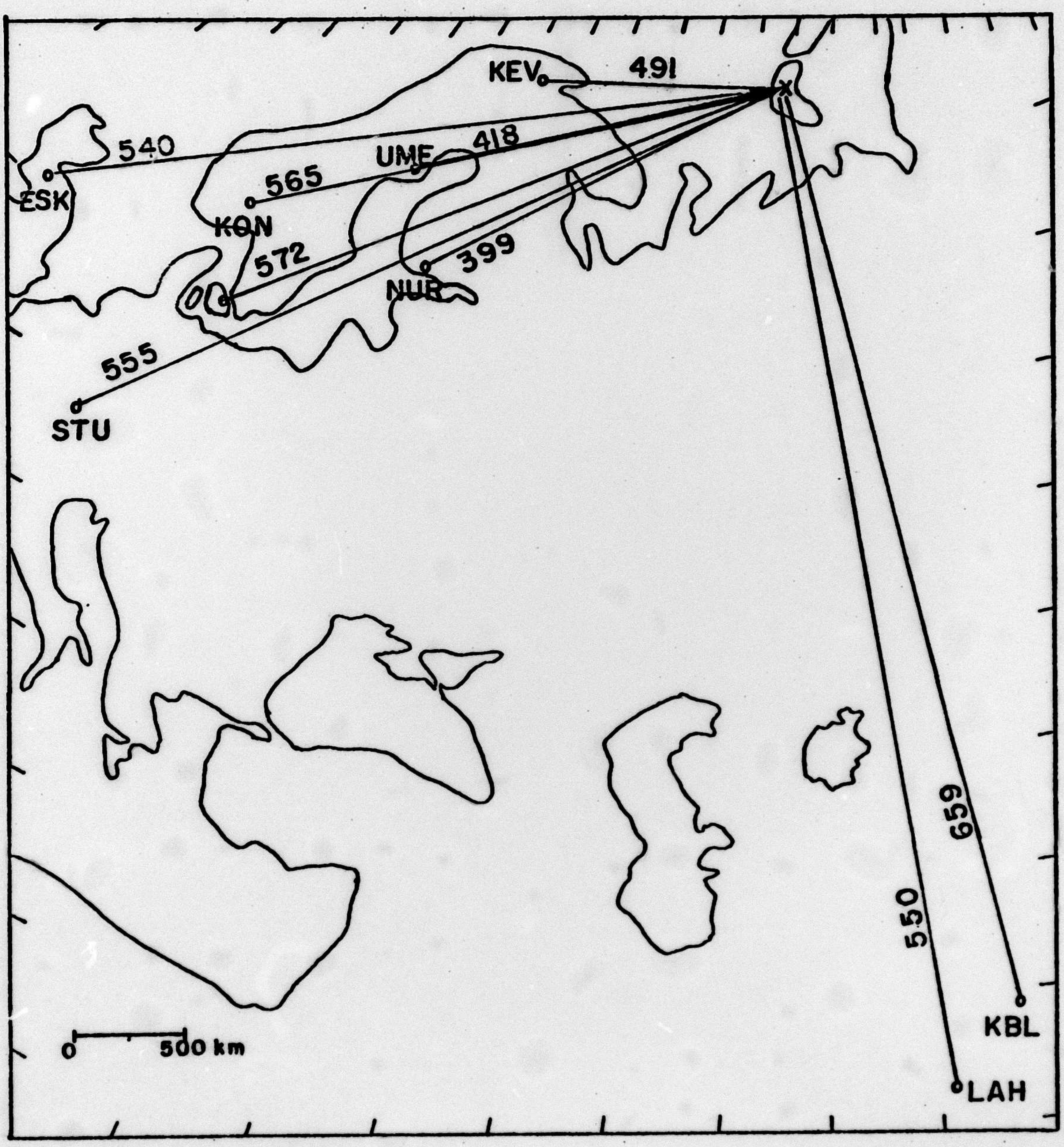

Figure 1. Q_o values for 1-Hz Lg waves from explosions at Novaya Zemlya obtained using the coda of Lg waves (ζ assumed equal to 0.2). An average epicenter is used for the various explosions considered.

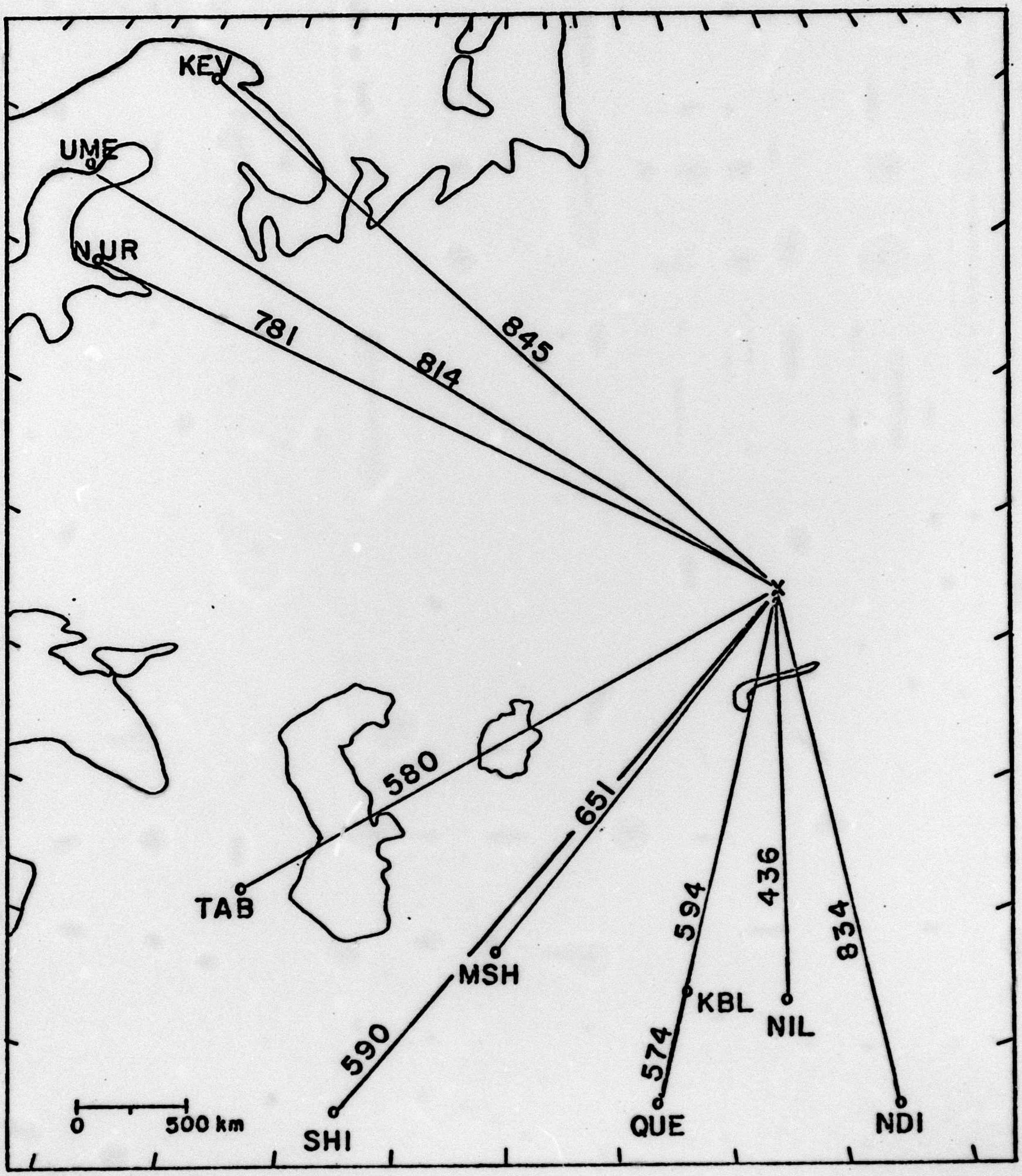

Figure 2. Q_0 values for 1-Hz Lg waves from explosions at eastern Kazahkstan.

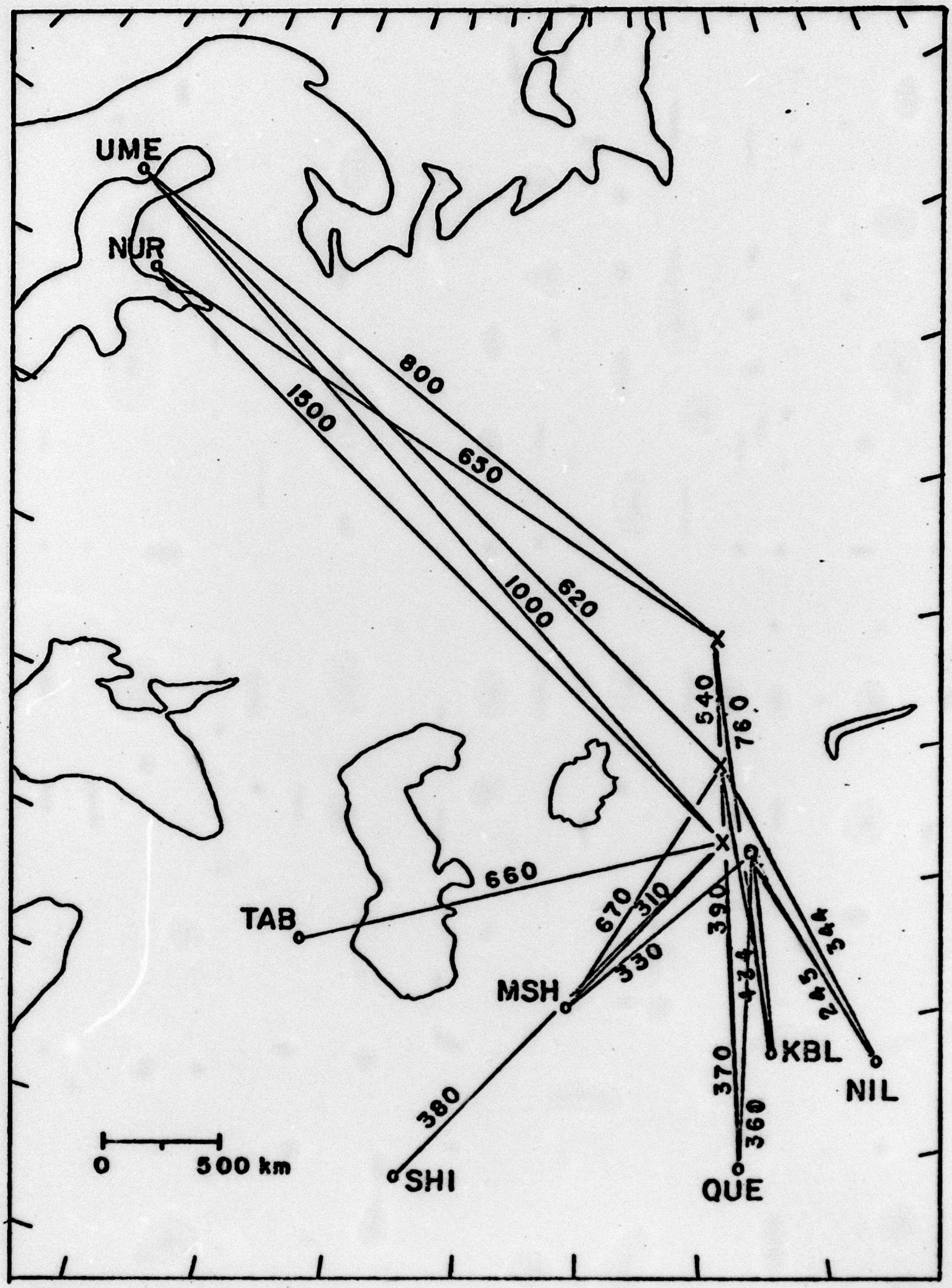

Figure 3. Q_0 values for 1-Hz Lg waves from explosions (X) and an earthquake (Q) in central Kazakhstan.

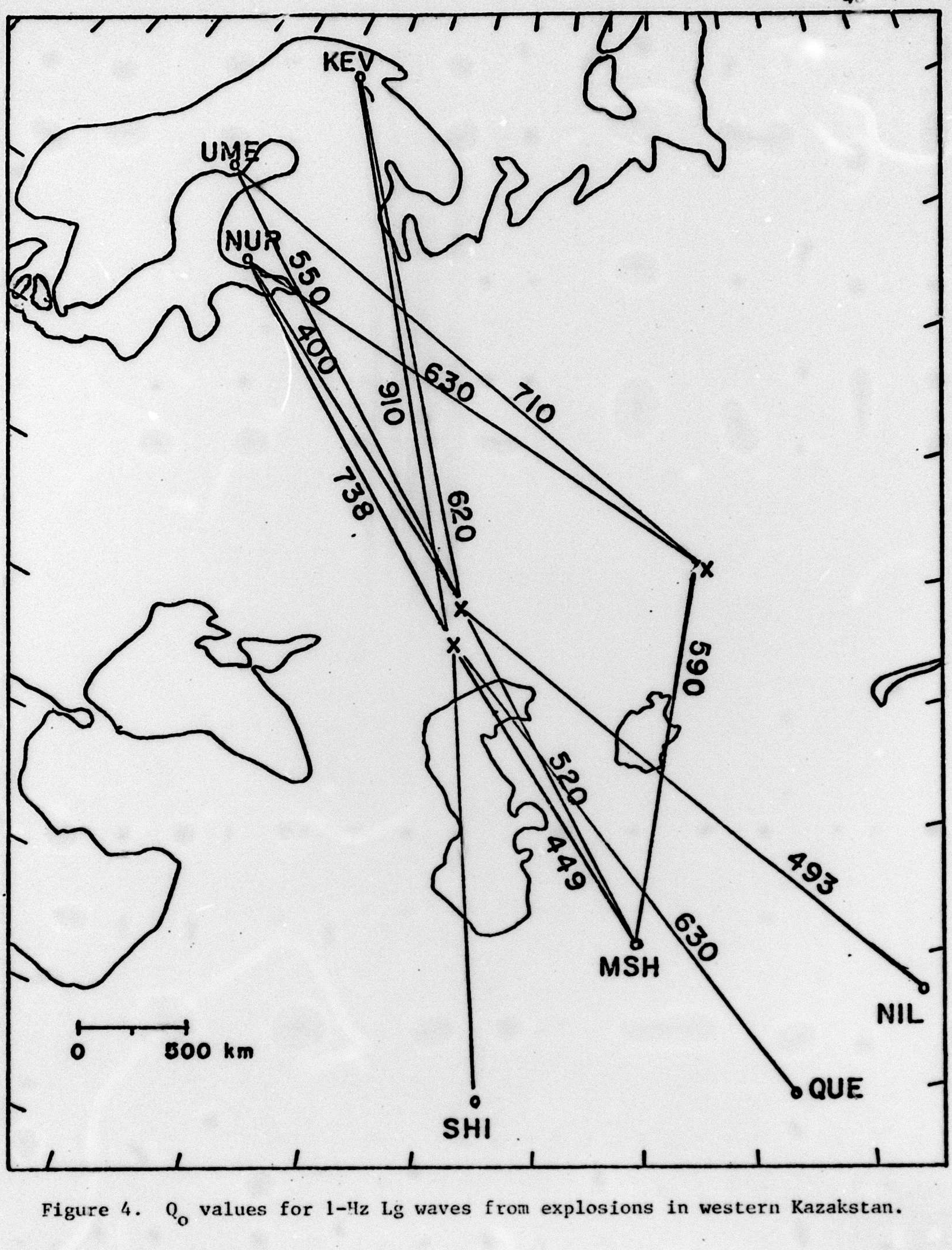

Figure 4. Q_o values for 1-Hz Lg waves from explosions in western Kazakstan.

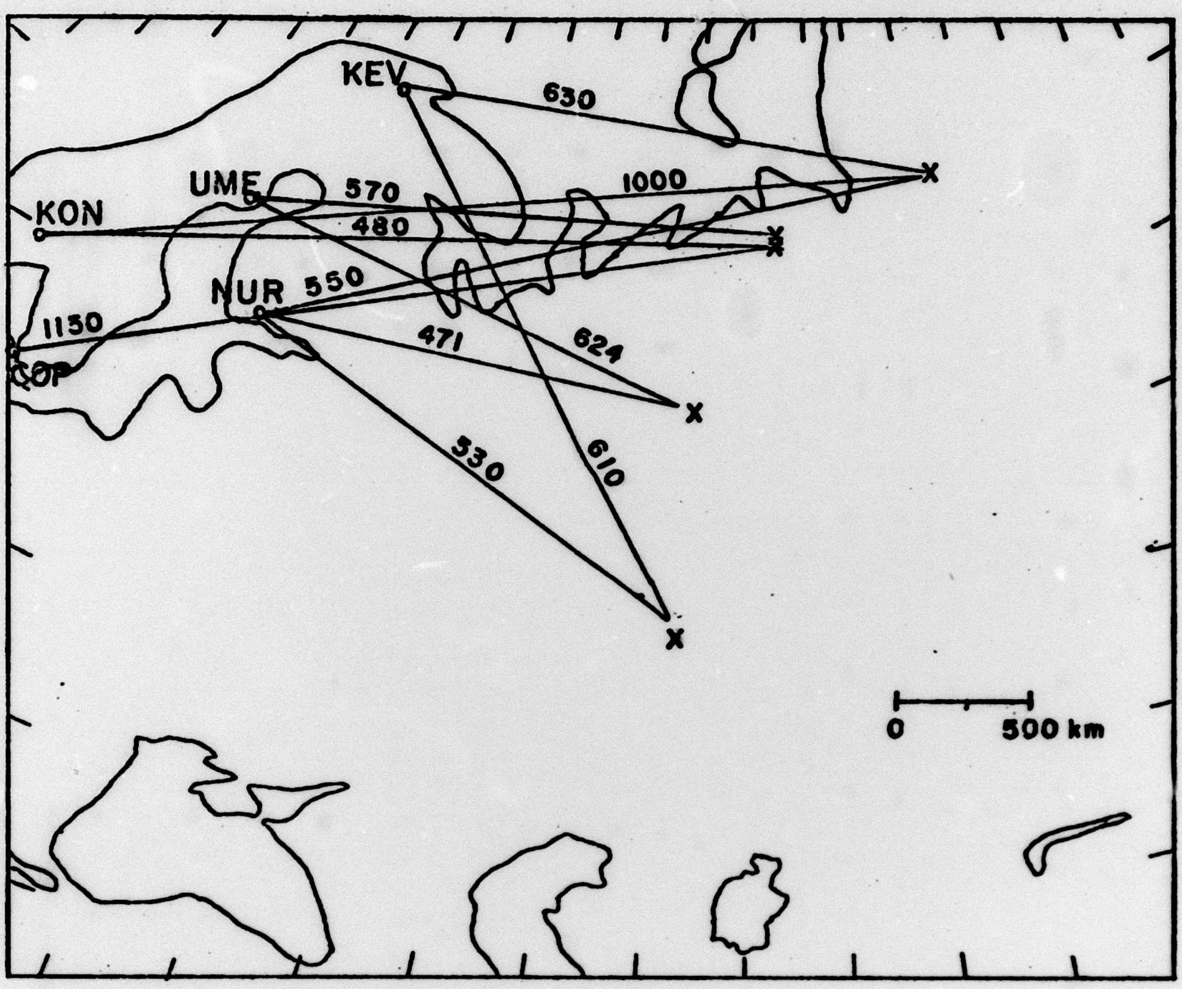

Figure 5. Q_o values for 1-Hz Lg waves from explosions in the Ural Mountains and western Siberia.

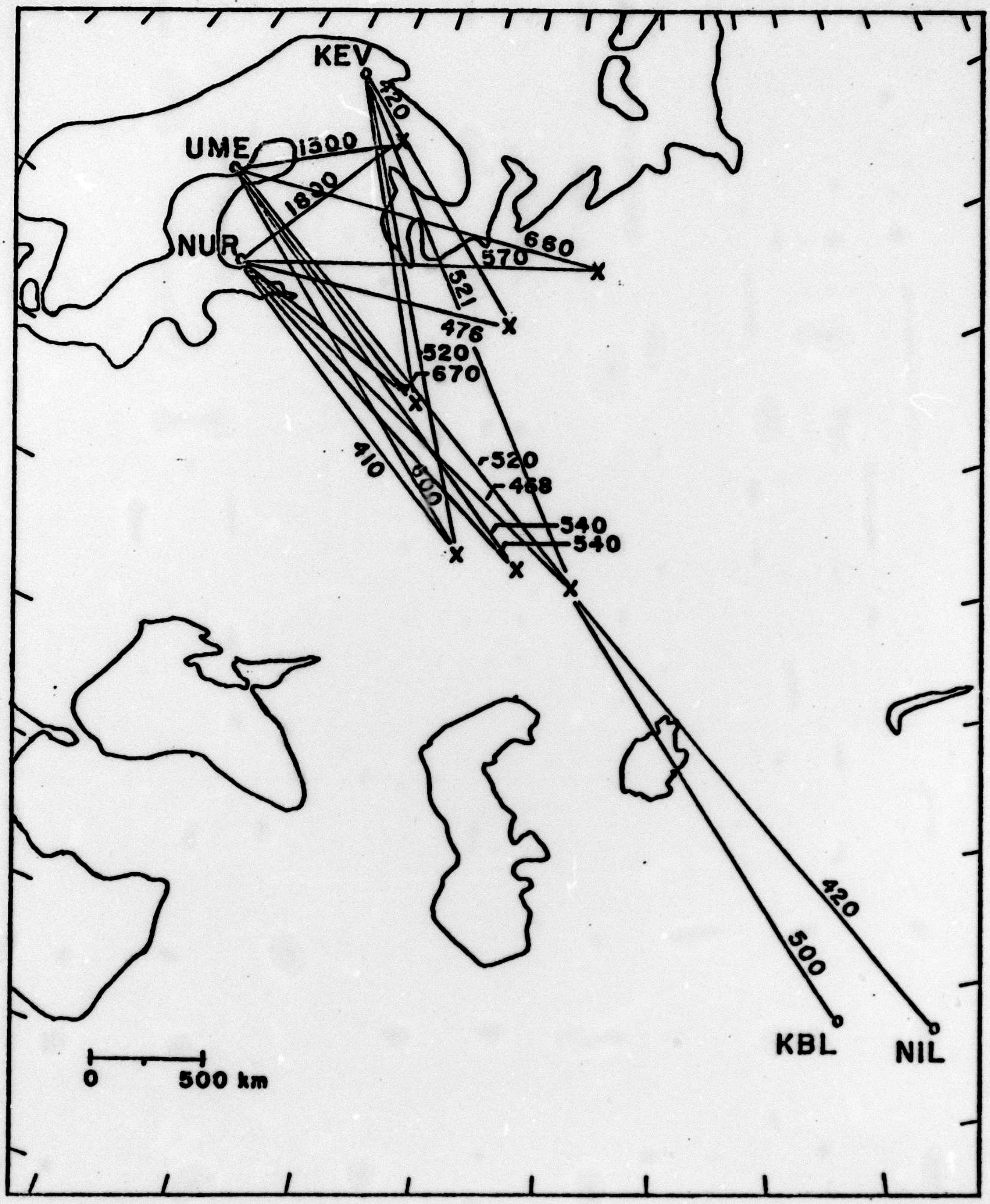

Figure 6. Q_o values for 1-Hz Lg waves from explosions in western Russia.

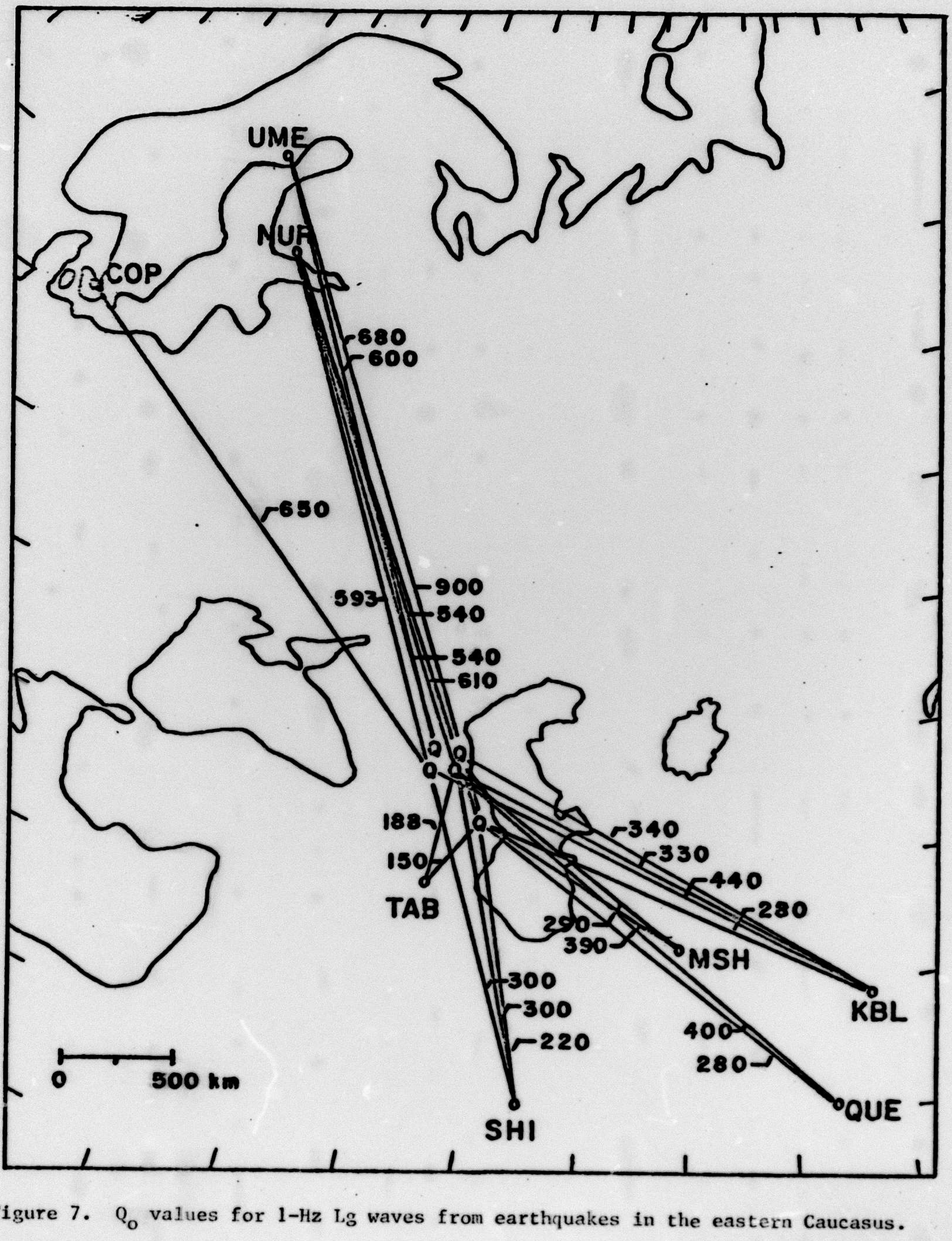

Figure 7. Q_o values for 1-Hz Lg waves from earthquakes in the eastern Caucasus.